

Mechanical Properties of Resistant Metal Protection Fences Processed with Novel Technologies: A Case Study of Fences Manufactured by Iran Pars Baft Company

Abstract

The essential requirements to protect the environment and structures have led to the development of a wide variety of protection fences. To achieve the best output, these fences need to be processed and manufactured in a way that they exhibit high resistance to impacts and tensions. Therefore, many companies have globally ongoing to manufacture these fences, each of which offers special technical and mechanical characteristics. However, in some cases, the quality of manufactured fences is not satisfactory. For this to be overcome, Pars Baft Company (PBC) has designed and manufactured metal fences possessing unique technical and resistance characteristics for use in various projects and for protection purposes. By performing a series of experiments and software analyses, this study investigated the technical and mechanical properties of a protection fence manufactured by PBC. For this, impact tests were conducted on protection fences by changing the height of the posts and positions of collision to precisely evaluate the fence's impact energy absorption capacity. In all experiments, the protection fence exhibited an astonishing capacity to dissipate the impact energy of 50 kJ following a rational arrangement of energy absorbers that causes effective slippage of wire ropes. Furthermore, the simplest likely assumptions employed in numerical simulations were meticulously proposed in terms of choosing finite element shapes, constitutive rules, and contact conditions, such that the numerical simulation model can efficaciously reproduce the dynamic behavior of the protection fence. It can be concluded that PBC protective fences can possess the best performance under full-scale tests to achieve improved capacity for energy absorption.

Keywords: *Metal fence, Protective fence, Mechanical properties, Iran Pars Baft Company*

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1. Introduction

The adverse outcomes of natural hazards have continually been a concern due to their detrimental effects on infrastructure, properties, and human lives. To deal with these outcomes, protective structures such as protection fences have been manufactured in recent years. The main advantages of the protection fences are their fast installation and easy maintenance [1, 3, 6]. A wide variety of protective fences are developed in many countries such as Japan, Italy, Switzerland, France, and the USA, among others. In Europe, various types of fences are developed for establishing many practical designs and construction solutions, and to set guidelines to approve rockfall protection kits. Chain link fence is a type of metal mesh woven from wires, in which wires run vertically and are bent into a zig-zag pattern. The annular ring runs vertically and builds a lattice pattern with square or rhomboid springs. Iron mesh fences typically provide acceptable durability and performance when fencing commercial (i.e., construction workshops) and residential (e.g., yard walls) areas, but they can be the best candidate for fencing around parks, gardens, and agricultural lands, and for preventing rockfall events, etc. [2, 4, 7]. This need especially holds for valuable and susceptible elements at risk such as transport routes [5-7], railways [8], or even urban settlements [9]. During the past decades, the knowledge and technology for passive mitigation measures have been substantially upgraded, particularly referring to rockfall flexible barriers (also known as net fences) [10,11].

Numerous novel devices and assembly methods have been recently designed. These differ not only in the resistant static scheme and the process they dissipate and transfer impact loads [12-14] but also serve to enhance the effectiveness of the protection and the efficiency during the expected working life [15]. Since the 1980s, net fences have been regarded as protection kits. Thus, their performance has to be investigated regarding their crucial characteristics (e.g., energy absorption capacity, height, and maximum elongation) [16, 17].

The most popular designs rely on a "performance-based procedure". In simple terms, and according to the results of the rockfall propagation analyses, a proper commercial product is selected [17] among the products whose energy absorption capacity and the nominal height (which are evaluated with the standard procedure [19]) are greater than the correspondent impact energy and passing height of the simulated blocks. This technique reflects two likely failure modes: the falling block trajectory is higher than the barrier height, or because its energy is larger than the barrier capacity. Nonetheless, this technique does not directly reflect the impacting conditions (e.g., the position and the angle of impact with respect of the net or the posts), as well as the shape of the impacting block [20, 21].

To consider all these uncertainties, each protection kit is classified based on energy absorption categories. More complex analyses and studies conducted through Finite Element Method (FEM) or Discrete Element Method (DEM)

modeling approaches [see, e.g., 22-28] enhance our understanding of the dynamic interaction between the block and the structure and the transfer load process. However, these computationally difficult techniques offer profitable solutions for designing more efficient devices or assembling single components, which are more useful for the producer rather than being affordable for the designer. Similarly, meta-model techniques [21, 29] which require outputs derived from either precise numerical models or experiments are designed for specific products and, thereby, can be inconvenient for general design purposes. To design mesh fences resistant to kinetic collisions, some critical aspects for the design of rockfall net fences have been recently highlighted and fixed through a time-integrated reliability-based approach [26]. It is possible to determine the design kinetic energy and passing height of the impacting block from the results of the performed trajectory analyses by choosing a proper failure probability. The reliability approach enables us to consider the random nature of the parameters influencing the system's performance and safety [27]. In this specific case, it provides probability distributions of the parameters of the impact and, theoretically, of the resistance. The technique further accounts for the variability in the magnitude and the temporal occurrence probability of an impact, which are thoroughly site-specific [1, 32, 39].

Accordingly, developing designs based on various analytical programs plays a fundamental role in the study and design of protection fence structures. These programs allow us to appropriately and logically verify and compare impact characteristic values such as impact force, displacement, kinetic energy, and so on. Therefore, the concern about passive mitigation measures has become a critical issue in rockfall risk management. Thus, considerable research has been concentrated on the development of new technologies in the past decades. Of all these structures, metal mesh fences and embankments are the most effective solutions for events characterized by high energy and/or high trajectories. However, designing these protective measures is still disputed, and for both of these reasons, a standard method is yet lacking. Taking note of the above, this study investigates the mechanical properties of resistant metal fences processed with novel technologies to be used for protection purposes.

2. Methods

The structure of the fence consists of steel posts STK400 with diameters of 90 mm and thicknesses of 4.5 mm. The fences concerned in this study are manufactured in Iran Pars Baft Company (PBC) with a wire size of 4.5 mm, a mesh size of 90 mm (according to Japanese industrial standards – JIS G 3547)) and a height of 100 to 300 cm.

Wire meshes (type Z-GS7) were designed and made from galvanized iron wire with a diameter of 4mm. The weight

employed to emulate the rockfall as it impacted the fence was a 2-kg reinforced concrete (RC) block that fell along an arc from a height of 30 m. Experiments were conducted for various positions of applying the impact forces (i.e., A, B, C, and D) and the heights of the posts (100 to 300 cm) (Figure 2). The tension of the rope was 10 kN. Figure 3 shows the positions of energy absorbers.

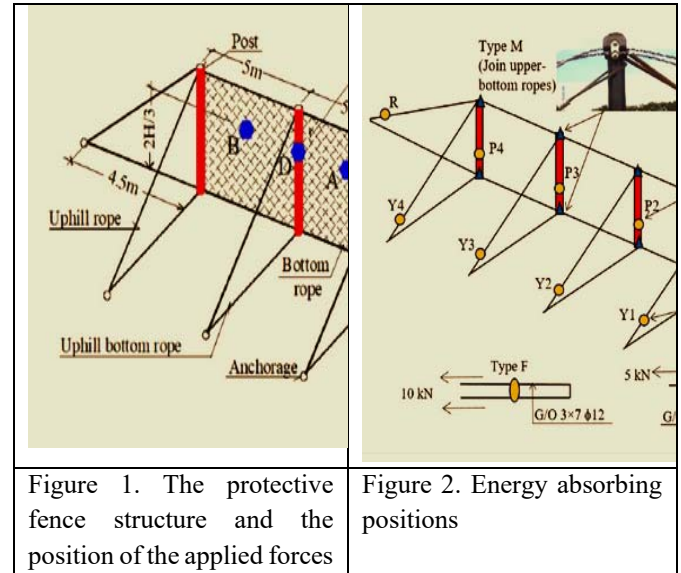


Figure 1. The protective fence structure and the position of the applied forces

Figure 2. Energy absorbing positions



Figure 3. The structure of fence used in the study

The fence was placed on sand and various devices were installed to verify adequately the dynamic behaviors of the protection fence under impact. A high-speed camera was placed in front of the fence to allow the characterization of the overall fence behavior and the estimation of deformation. The post-impact slipping length of the wire rope was measured exactly with the use of energy absorbers.

Regarding the impact tests, two cranes were employed in the experimental procedure, the first of which (600 kN) lifted its top to the center of the arc of the prescribed rock's motion, and the second of which (300 kN) pulled the RC block up to the specific height.

3. Results

3.1. Displacement and impact force effects

Figure 4 shows the results for displacement and impact force effects. In all tests, the protection fence (span width of 5 m and

post heights of 2 and 3 m) successfully absorbed the impact of energy of the order of 50 kJ. The fence's maximum displacement at position C (Cases 1-3) was nearly 3.5 m, and this number ensures the safety of the design of the protection fence, as its structure was firmly established with no breakage in the wire nets or wire ropes after they absorbed the impact energy. Moreover, when the RC block directly impacted the posts at position D (Cases 1-4 and 2-4), the deformation angle of the post at a height of 3 m tended to be larger than at 2 m. These angles were 54° and 84°, respectively, suggesting that posts at a higher height can perform worse regarding their deformation response under direct impact.

	1 A /1	1 B /2	1 C /3	1 D /4	2 A /1	2 B /2	2 C /3	2 D /4
Impact force (kN)	29	27	20	24	1	0.4	0.5	0.5
Maximum displacement (m)	3.3	2.8	3.5	0	3.4	3.1	0.08	0.04
Residual height (m)	0.9	0.9	0.7	1.2	1.9	0.7	0.1	0.5
Remarks	0	0	0	0	0	0	0	0

Figure 4. Results for displacement and impact force

Regarding the residual height of the metal fence, it demonstrated a descending trend compared to the initial impact in Cases 1-1 and 2-1, and the repeated impacts in Cases 1-2, 1-3, and 2-2. This phenomenon was applicable to the elongation of the wire net and wire ropes, as well as to the movement of anchorages. Moreover, the change in post height was studied to evaluate the post-impact effectiveness of the test models. When comparing this change for Cases 1-1 (1970-910 mm) and 2-1 (3000-1890 mm), which only involved the initial impact, the rate of reduction in the metal fence's height was nearly 50% (for the Case 1-1) and 40% (for Case 2-1). As expected, the protection fence with a 3-m post can respond more successfully when the collision occurred in the middle of the span. It can be supposed that the residual heights of the fence depend on the change of the post's height, with smaller residual heights that are achieved in higher post heights.

Figures 5 and 6 show the relationship between impact force, displacement, and absorbed energy. Here, due to measurement failure, the data of the fence at a height of 3 m are not available. The values of impact force were calculated by multiplying the obtained acceleration with the mass of the rock. Based on the relationship between absorbed energy and displacement in

Cases 1-1 and 1-4, a rapid growth of absorbed energy was reached up to the point at which the maximum displacement was reached.

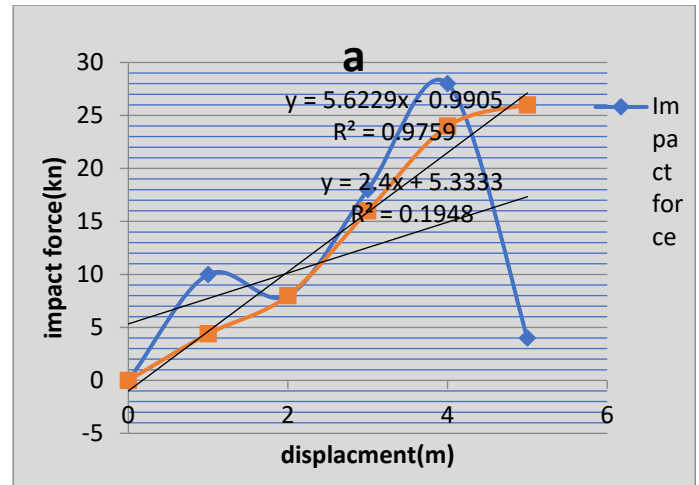


Figure 5. Relationships between impact force, displacement, and absorbed energy for Case 1-1

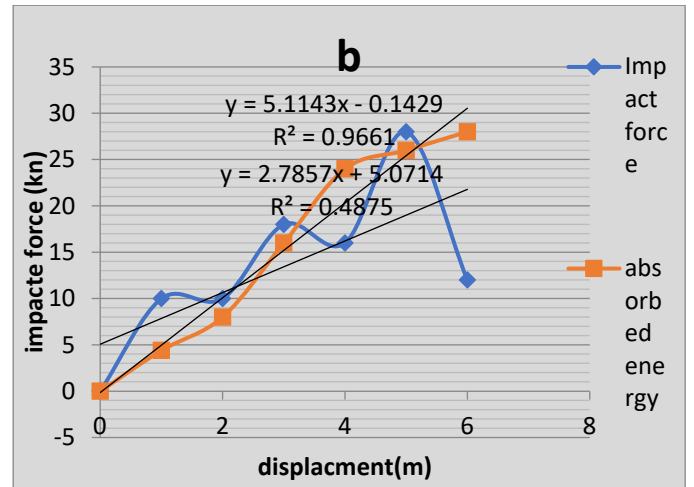


Figure 6. Relationships between impact force, displacement, and absorbed energy for Case 1-4

2.3. Tension of the rope

Figure 7 shows the position of the wire ropes, and Figure 8 illustrates the time history of the rope tension. Similarly, the maximum values of the rope tension are summarized in Figure 9.

Based on the results of all experimental cases in Table 2, the lateral rope (t6) shows the greatest tension of nearly 13.99 kN in Case 2-2, while the maximum tension of an uphill rope (t3) is 10.55 kN in Case 1-1.

It can be said that the maximum rope tension value is obtained when the impact occurs at the middle point of the span, at positions A and B. Moreover, the rope tension tends to increase substantially compared to the rope tension for the fences that consisted of posts with heights of 2 and 3m, as the protection fence is set up with higher posts, and the height of the impact point was correspondingly set at a higher location.

Figure 8(a) and (b) show the comparison of the rope tensions of (respectively) Cases 1-1 and 2-1 involved impacts at the center span. This figure indicates that the rope tension exhibited nearly the same fluctuation. Furthermore, using a short time span to increase the maximum tension also yielded the same fluctuation at nearly 0.2 s. Likewise, a rise in the rope tension of the lateral and uphill ropes ($t1 \div t6$) was more abrupt compared to that of the bottom lateral and bottom uphill ropes ($t7 \div t12$). Thereby, the bottom ropes were needless for the installation of energy absorbers of type F, while absorber installations at the lateral and uphill ropes became effective in limiting their tensions.

According to Table 2, when the RC block impacted directly the post in Cases 1-4 and 2-4, the rope tension reached the maximum values only in ropes $t4$ and $t10$, as these ropes linked directly to the post. Additionally, the initial impacts of Cases 1-1 and 2-1, and the repeated impacts of Cases 1-2, 1-3, 1-4, 2-2, 2-3, and 2-4, were evaluated, with the results summarized in Table 2. The results imply a fast descending trend in the rope tension for the cases of repeated impact. This phenomenon was due to the elongation of the wire ropes and the movement of anchorages. To hold uphill and bottom ropes in experimental models, anchorages were reinforced on a sand background. The boundary condition was not rigid. Thus, the anchorages occurred in the small-scale movement under repeated impact.

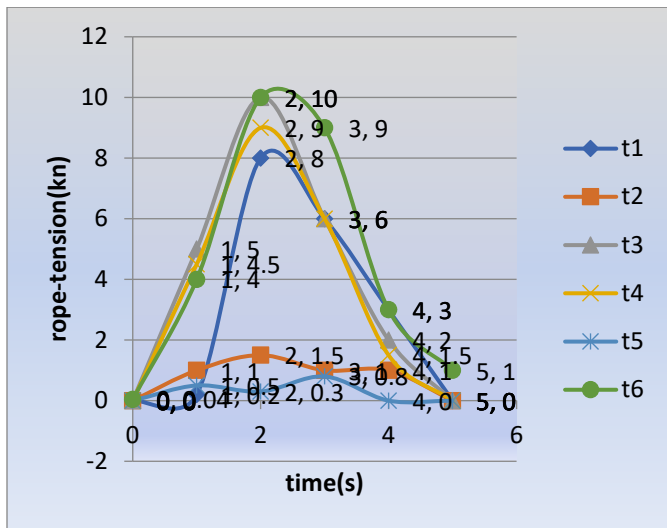


Figure 7. Time curve of rope tension for Case 1-1

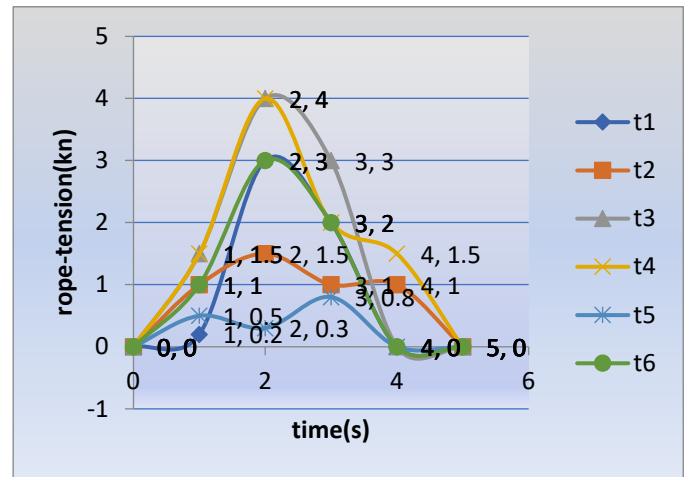


Figure 8. Time curve of rope tension for Case 2-1

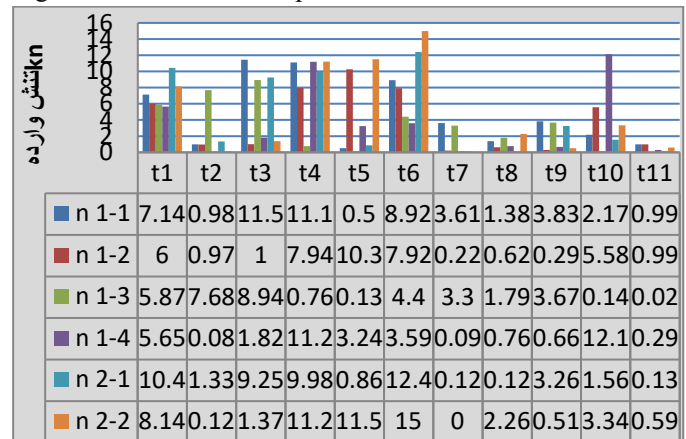


Figure 9. Maximum tension of wire ropes (kN)

3.3. Energy absorbers

The slipping length of the wire ropes and energy absorption are given in Figure 10. The energy absorption value for these devices can be measured by the multiplication of the total slipping length with the tensions of 5 and 10 kN, respectively. According to Figure 10, the slipping of the wire ropes through the energy absorbers of type F did not occur in many experimental cases. This is because this phenomenon only involved the positions of energy absorbers next to the impact area.

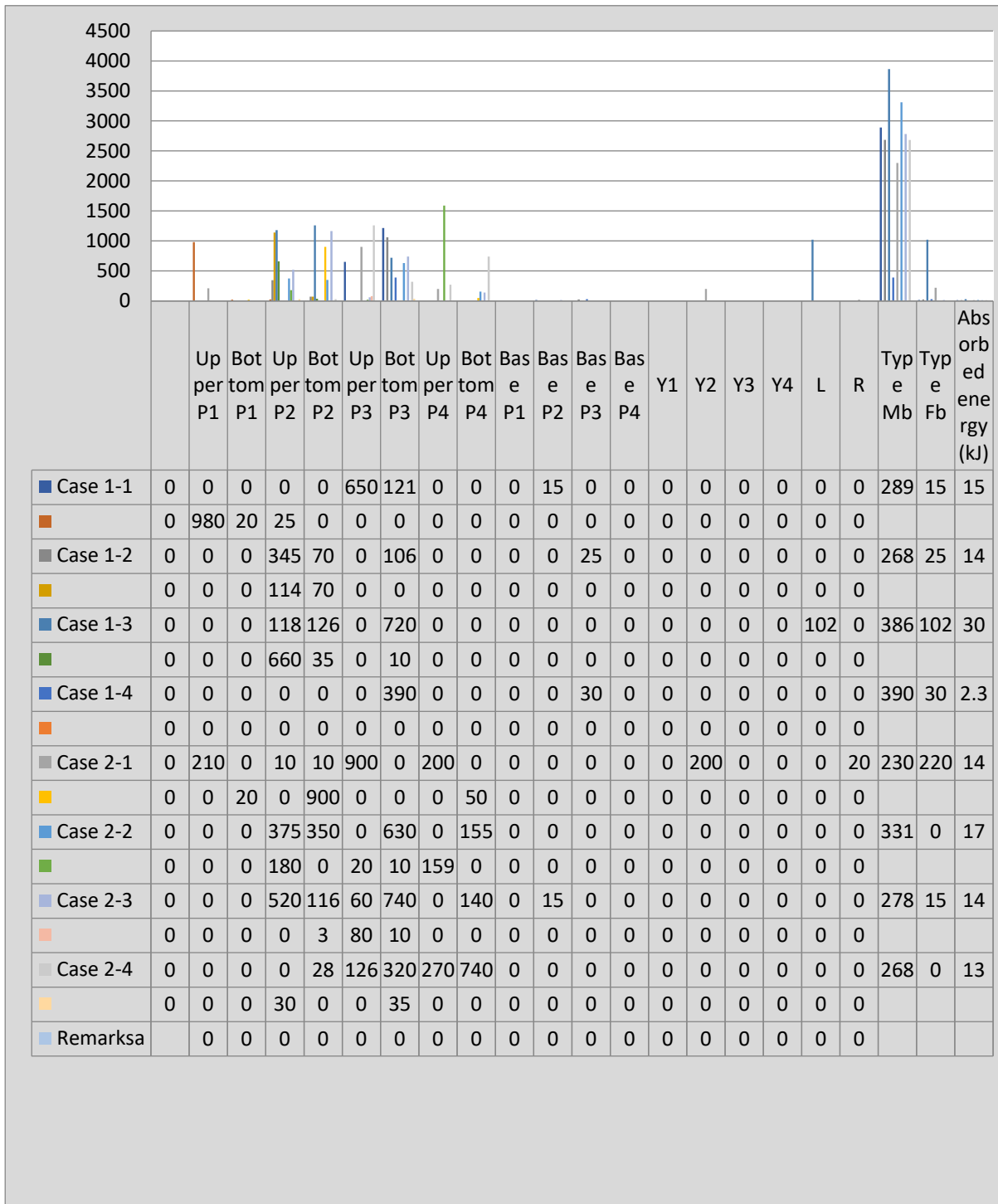


Figure 10. Slipping length of wire ropes and energy absorption.

3.4. Slipping length of all wire ropes for absorbers of types M and F

When comparing the total slipping lengths for the absorber (type M) for their initial and repeated impacts, the length was found to be substantially enhanced. For example, the initial impacts correlated with Cases 1-1 and 2-1 resulted in slipping lengths of the order of 2.99 and 2.40 m, respectively, while the wire ropes slipped by 3.86 and 2.78 m in the repeated impact

Cases 1-3 and 2-3, respectively. This can be due to the fact that the bolts and nuts of the metal block can be worn out by friction arising from the tension of the upper and bottom ropes when collisions occur repeatedly. Thus, it is suggested to replace energy absorbers in the experimental cases in terms of repeated impacts.

Considering the initial impact, the fence with 2m posts in Case 1-1 absorbed 14.70 kJ with type M and F absorbers, while 13.70 kJ was absorbed by the fence with 3m posts in Case 2-1.

For more clarification, it can be said that the energy absorptions of the absorbers types M and F were not significantly different when the post height changed from 2 to 3m. In addition, the least value of 2.25 kJ was absorbed in Case 1-4, where the RC block impacted directly the post. Notably, not only the impact energy was absorbed by these devices (types M and F), but it also was absorbed by the deformed post.

4. Conclusion

This study conducted a series of impact experiments to verify the performances of PBC protection fences for rockfall events with an impact energy of 50 kJ while altering the heights of the posts and collision positions. Moreover, the numerical models of the protection fence were modeled efficaciously. Thus, these models can assist or replace the full-scale tests. The results are presented as follows:

- 1) In all cases, the fence (with 2 and 3 m posts and a span width of 5m) effectively absorbed falling rock with a 50-kJ impact energy at various impact positions.
- 2) The fence's maximum displacement reached 3.5 m approximately with no breakage of the wire net or wire ropes after it absorbed the impact energy.
- 3) After the rockfall directly impacts the posts, the post's deformation tended to increase with a rise in the height of the posts and the impact energy was absorbed by the absorbers type M and F and the deformed post.
- 4) The protection posts of the fence with heights of 3m could respond more effectively when the collision occurred in the middle of the span in the case of the initial impact, such as in Case 2-1.
- 5) The maximum impact forces of the protection fence that corresponded to the impact energy of 50 kJ are nearly equal in the cases of the numerical analysis and experiment.
- 6) The slipping behaviors of the wire ropes through the energy absorbers and the movement of anchorages reduced the rope tension. However, these forces enhanced when fences with 2 and 3m posts were compared.
- 7) The energy absorbers should be replaced in the experimental cases in repeated impact paradigms due to the damage to the bolts and nuts of the metal block.

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